

Narendra Mohan
Priyanka Singh *Editors*

Sugar and Sugar Derivatives: Changing Consumer Preferences

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Foreword

It gives me an immense pleasure to write foreword to this book entitled *Sugar and Sugar Derivatives: Changing Consumer Preferences* by Prof. Narendra Mohan, Director, National Sugar Institute, Kanpur, jointly authored with Dr. (Mrs.) Priyanka Singh, Scientific Officer, UP Council of Sugarcane Research, Shahjahanpur.

Change is the law of life and those who look only to the past or present are certain to miss the future. Change is inevitable. Growth is optional. The task of forecasting “Changing Consumer Preferences” becomes all the more challenging, when consumer is a human being and it involves his desire for constant change, for better living. Further, emergence of newer and increasing knowledge leads to growth of not only existing but also newer wants.

In such a complex scenario, I personally believe that ability to foresee ahead of others, the futuristic scenarios of a currently prevailing want of a consumer and to recommend a road map to address his changing preferences is the characteristics of only few gifted individuals.

It is in this backdrop that one must recognize and appreciate the importance of the initiative taken by two gifted individuals, Prof. Narendra Mohan and Dr. (Mrs.) Priyanka Singh, in bringing out the book *Sugar and Sugar Derivatives: Changing Consumer Preferences*.

Prof. Narendra Mohan with a mature blend of youthful energy and never ending quest for combining his own expertise with a magnificent obsession of identifying and assimilating the knowledge and expertise available not only in India but also elsewhere in the world is in the recent times perhaps the best gift to Indian sugar industry in general and to National Sugar Institute in particular.

Dr. (Mrs.) Priyanka Singh is currently the Scientific Officer, UP Council of Sugarcane Research, Shahjahanpur, and an eminent scholar with a highly distinguished academics and recipient of “Woman Scientist Fellowship” award from the Department of Science and Technology, Government of India. She is a recognized authority on the subject of “Sustainable Sugarcane Production” and an author of more than 40 research papers in diverse areas connected with sugarcane.

This book which is a collaborative effort of such eminent authors could not have found better authors. The contents of this book practically encompasses not only all aspects of present practices and scenarios of sugarcane growing, processing into conventional end products such as sugar, power, ethanol, but also traverses into the

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near future as well as far ahead into the future and visualizes innovative improvements in agronomy, technology for enhancing significantly improved efficiency, productivity, and economics of production. Further, it identifies a large number of downstream value-added diversifications for overall economic sustainability and growth of sugar industry in the coming years.

We all are aware that India is an agrarian society, and sugar industry is the second largest agro-based industry in India. The sugar industry during the last seven decades has revolutionized the rural economy and landscape and brought in a high degree of socioeconomic benefits to rural India. In order to enhance and sustain this growth story, it is not only essential to continue to focus and support in every possible manner by providing scientific and technological support, but also to continually identify newer avenues for newer products and applications for the usage of sugarcane and fructify them into commercial use to meet the changing requirements of the consumer or create a new choice or demand for a consumer by introducing a new product or process.

I once again wholeheartedly compliment the authors for such an excellent book and also compliment all the contributors for the variety of topics contained in this book, and do sincerely hope that this becomes a guiding light for currently uncharted future.

Deccan Sugar Technologists' Association
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S. S. Gangavati

Preface

Sugarcane occupies a commanding position as an agro-industrial crop and is commercially grown in about 115 tropical and subtropical countries of the world. However, volatility in sugar prices is leading sugarcane industries worldwide to broaden their revenue base by moving from a single commodity manufactured to one of renewable biomass for the production of a broad range of value-added products. The comprehensive use of sugarcane through its by-products and other value-added products is one of the major lines of action that sugar-producing countries are attempting these days for its sustainability. The concept of cane diversification involves its agro-industrial utilization in environmentally friendly alcohol, alcohol derivatives, bioenergy, antibiotics, bio-based chemicals, surfactants, paper and residue recycling for sustainable agriculture to maintain an eco-friendly environment. For many years, sugarcane was regarded as a single product crop, i.e., sugar, and its actual potential was not recognized by the sugar industry. Manufacturing allied products was a discretion rather than a necessity and the by-products were not judiciously utilized for value addition and for safeguarding the environment. However, scientific and technical experiences accumulated through years of intensive research in the field of by-products and co-product utilization in many countries have given a new ray of hope to the sugar industry for its sustainability, especially in developing countries. It has therefore become necessary that the sugar industry, which has been so far processing the sugarcane mainly for sugar, should now focus on the establishment of sugar-agro-industry complexes. The book will provide a complete knowledge of the potential use of the sugarcane crop not only as a source of sweetening agent (sugar, different types of sugar, sugar derivatives), but also for many other uses including a source of bioenergy.

Further, it is important to mention that with the increase in added sugar consumption, consumers are now tempering their love for sugary foods in response to global recommendations to limit calories from added sugars. In fact, a recent study found that 57% of respondents were trying to limit or avoid sugars in general. This significant shift may be influenced by a variety of factors like lifestyle trends focused on healthier lifestyles and cleaner eating and media and healthcare messaging linking excessive sugar consumption to obesity and health concerns.

There is another side to the coin throwing light on various sugar taxes that are being imposed by various countries on foods and soft drinks with the aim to curb

consumption of sugary products so as to tackle obesity and reduce public health costs. On the contrary, marketing literature offers a plethora of evidences relating to sugar consumption and its co-relation with obesity. Studies indicate that in several countries even though sugar consumption has been flat or reduced obesity ratios have been rising ever since. Such patterns are attributed more towards the lifestyle of the common man rather than its sugar intake, in context, sweeteners, low calorie, in particular, are gaining popularity. Thus, understanding the dynamics and structure of sugar consumptions is vitally important in assessing the future of the world sugar economy. The chapters covered in this book will showcase that the fundamental cause of obesity and overweight is an energy imbalance between calories consumed and calories expended, and it will also burst the myth related to the calorie content of sugars.

This book will not only discuss and showcase the possibility and means of diversification of sugarcane as it has become a global necessity due to unstable prices of sugar in the international market but will also focus on various innovations and technologies developed and developing regarding sugar, sugar derivatives, and sugar industry by-products for their possible utilization in developing sugar-agro-industry sustainability.

We hope this book will serve as an important reference and will be of benefit for students, scientists, industrialists, and entrepreneurs involved in sugarcane and sugar sectors and stimulate research and extension work on burning issues of sugarcane, sugar, and related products, and it will enlighten the planners and executives in deciding the national and international policies related to sugar industry.

Kanpur, India
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Sugar and Sugar Substitutes: Recent Developments and Future Prospects

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Priyanka Singh, Y. G. Ban, Lenika Kashyap, Archana Siraree, and J. Singh

Abbreviations

CF	Crystalline fructose
CSPI	Center for Science in the Public Interest
FDA	Food and Drug Administration
FOS	Fructooligosaccharides
GFS	Glucose-fructose syrup
GI	Glycemic index
GRAS	Generally recognized as safe
GS	Glucose syrup
HFCS	High-fructose corn syrup
HFS	High-fructose syrup
HIS	High-intensity sweeteners
LIS	Low-intensity sweeteners
NHDC	Neohesperidin dihydrochalcone

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4.1 Introduction

Sugar is very helpful in giving short bursts of energy. It is a form of simple carbohydrate which is generally associated with sweetness, and as soon as we take in a dose of sugar, it gets converted to glucose and is efficiently absorbed by the cells in the body, giving us that sugar rush. For this reason, many sportsmen and even people who work vigorously and need energy instantly always keep with them some sugar cubes or chocolate bars that have high sugar content, as it provides instant energy. Sugar is considered to be an important facilitator of our bodily processes and is an essential ingredient in one's diet. However, sugar is largely seen as an unhealthy component of the diet that should not be consumed because of the diseases associated with it; however, not consuming sugar at all is not the sole remedy to escape diseases that are caused by high levels of sugar. Even deficiency of glucose causes our body to overreact when there is a small intake of glucose. Hence, maintaining a balanced level of glucose (sugars) is recommended whenever possible, and it should neither be high nor low. Sugar continues to be the most popular sweetener. However, there are other natural and artificial compounds that are sweet at much lower concentrations, allowing their use as non-caloric sugar substitutes. A sugar substitute could be either from a natural source or artificially derived. Artificial sweeteners are low caloric. Sugar substitutes are bulk and intense. Intense sweeteners are artificial one, synthesized from a variety of starting materials. These are intense as their sweetness is a hundred or even thousands of times sweeter than sucrose or white sugar. Food sector includes bakery, dairy, confectionery and packaged foods and is growing because of rising customer preferences and increasing knowledge of low-calorie foods. In recent years, the usage of sugar substitutes such as stevia, aspartame, cyclamate and others has increased due to the increasing awareness among the overweight and diabetic population about food consumption. Sugar alcohols are the most common sugar replacements which have a fraction of the sweetness of sucrose. Some other amino acids are perceived as both sweet and bitter. Sugoname is the sweetest chemical known. It is 200,000 to 300,000 times sweeter than sucrose (Hürter 2004). Although, most of the time, we are referring to the natural sweetener sucrose usually obtained commercially in crystalline form from sugarcane and sugar beet, besides these two major sources of sugar, sugar chemists have recognized more than a hundred sweet substances as "sugars" like sugar palm, sweet sorghum, sugar maple and some other crops, trees and vegetables. These alternative sweetener sources contribute about 1% of the world's total sugar production. In this chapter, we will discuss about different sources of sweetening agents, their nutrient content and mode of consumption.

4.2 Global Production and Consumption of Sugar and Sugar Substitutes

About 110 countries currently produce sugar from either sugarcane or sugar beet, and 8 countries produce sugar from cane and beet. On an average, sugarcane accounts for almost 80% of the global production of sugar. India, Brazil, Thailand, China, the USA, Mexico, Russia, Pakistan, France and Australia are the top 10 sugar-producing countries, and approximately 70% of global output is from these countries. World sugar consumption increased from 123,454 million tons to 172,441 million tons between the years 2001 and 2018 that is equivalent to an average annual growth of 2.01%. The major markets that consume sugar include India, the EU, China, Brazil, the USA, Indonesia, Russia, Pakistan, Mexico and Egypt. The key factors influencing white sugar demand comprise an increase in population, income per capita, the price of alternative sugar sweeteners and health-related debate (www.isosugar.org).

However, changing food habits among the consumers the world over, especially among the more developing and developed countries with a sizable middle-class population, is making sugar alternatives popular. This is largely because of the increasing awareness about the increasing number of healthy choices that are available. All this shows in the numbers of sugar substitute/alternative industry. The industry is expected to reach estimated revenue of 9.66 billion dollars by the year 2025. It is expected to grow at rate higher around 3.75%.

A lot of the demand for various substitutes depends on the strength, sweetness, components and overall quality of the substitute. For instance, high-fructose syrup forms a bulk of the sugar substitute industry holding 3.33 billion dollars in 2017 and expected to grow with a Compound Annual Growth Rate of 3.61%. Every year new substitutes are being formed, and they are then tested and passed by government agencies like the Food and Drug Association (FDA) in USA and similar agencies in other countries. Sugar substitute market is largely divided between high-intensity sweeteners (HIS) and low-intensity sweeteners (LIS). HIS accounts for 33.12% in 2017 and expected to grow with a high Compound Annual Growth Rate over the coming years. In 2018, the US Food and Drug Administration (FDA) has announced the companies to adopt its revised nutrition facts panel, which provides a low-calorie count and a new line for added sugars. Additionally, the growing consumption of low-calorie food is enhancing the growth of the segment (<https://www.kennethresearch.com/report-details/sugar-substitute-market/10220962>).

Along with this the beverage industry also forms a bulk of this demand largely because of the enormous (and perpetually growing) demand in the industry coupled with the need of constantly trying to lower the cost of production. The beverage industry with sugar substitute is dominating the market with 2.97 billion dollars in 2017 and is expected to grow with a Compound Annual Growth Rate of 3.27% every year. A shift to healthier sugar substitutes is also anticipated because of the increase and developments of the health drink markets like those of amla, pomegranate and other fruit juices along with sports drinks. Presently, the largest producers of these sugar substitutes are the USA and Canada; however, Asian manufacturing hubs such

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as China and Japan are also developing, and it is these sectors in Asia Pacific that are estimated to see the most growth.

4.3 History of Sweeteners

History of sugar dates back to 8000 BC where archaeological excavations have revealed that the cultivation of sugarcane first began in New Guinea by its residents (Sato 2014). They then slowly disseminated that know-how to other regions like South China, South-East Asia and the Indian subcontinent. Around 800 BC, the first evidence and reference of something resembling sugar is found in China (Paterson et al. 2012; Daniels and Menzies 1996). This record mentions India's sugarcane fields in their ancient texts that have survived over the years. Records of 300 years later show that Indians started making a cooled sugary syrup which was modelled into large, level bowls. This new morphological characteristic made it more convenient for transportation, and it became popular, so much so that even to this day, that name survives, and it is synonymous with candy—khandā. Two hundred years after that (around 300 BC), inhabitants of the European continent were first exposed to sugar during the rule of Alexander the Great, when the retreating troops carried with themselves a strange “honey powder”. However, it wasn't until the end of Crusades, over a thousand years later, that the Europeans truly embraced sugar and started its consumption on a large scale. Even in the Indian subcontinent, honey was preferred over sugar till the fifth century AD, when the Gupta Empire figured out the technique to convert sugarcane juice into granulated sugar particles. This made it convenient to transport and sugar became one of the primary trading goods (Parker 2011).

Around 500 AD, when Buddhist monks were travelling from India to China, they introduced sugar there, and about a century later, they set up their first sugarcane plantation based on the knowledge they had acquired from India (Rippe 2014). Likewise, sailors from India dispersed the word about this new and remarkable food item across the ocean. Later on, the ninth and tenth century represents a turning point in the history of sugar development, in the form of the Arab Agricultural Revolution. It was then that the Middle East Islamic nations adopted the method of making sugar from India, and then this brought sugar in contact with the Europeans on a wider scale. Soldiers took it back with them at the end of the Crusades as “sweet salt”. This marked the rise of the European trading fleets that brought huge amounts of know-how and raw ingredients to Europe, beginning the “Golden Age of Discovery” in the continent. In the sixteenth century, Central America witnessed its first sugarcane plantations, and in the early seventeenth century, Olivier de Serres, a French agronomist, first formed crystallized sugar from beets. Till this discovery, sugar was expensive and was inaccessible to the large parts of the population of Europe and the American continent (Newson 1993). However, the expansion of the plantations worldwide changed the landscape, making sugar a very popular and household product. This change, in turn, affected economic and social status in the world. For instance, these plantations and the need for intensive labour increased slave trade from the backward continent of Africa, intensifying the slave trade and

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spreading this unfortunate practice to large parts of the West (Draper 2017). At the beginning of the nineteenth century, Germany established the first beet sugar factory. This permitted the European continent to start the production of sugar in huge quantities, which, in turn, made the commodity cheaper and, hence, more accessible. By the end of that century, sugar, more than a “popular” ingredient, became more of a necessity in households and was included heavily in the mainstream diet.

In 1957, Richard O. Marshall and Earl R. Kooi first manufactured a high-fructose corn syrup that is now prevalent in a myriad of sweet products, for instance, sodas. Because of these, new low-calorie or no-calorie sweeteners have been created (Marshall et al. 1957). The saccharin, an artificial sweetener, was first introduced in the year 1886 (Fahlberg 1886) likewise, many other sweeteners were also created, some natural a few artificial, and research continues in this direction. New and progressive goods enter the market all the time to cope with customer demands. Many of these can have health advantage; however, time will inform us as the sugar history is around 2500 years old only.

4.3.1 Sweetener Consumption and Health

Discovery of sugarcane some 2500 years ago changed the sugar intake in humans from nil to refined form. Sugar and sweet consumption were popular from ancient times and were intrinsic to Indian culture, customs and religion. However, there has been a drastic shift in this regard only in the last couple of hundred years. The consumption of sugar is basically in the form of commercial sugar, jaggery or gur and khandsari. The average sugar consumption in the developing world by 1700 per capita was approximately 4 pounds per year, reflecting less than 1% of calorie intake (Table 4.1). By 1800, this had grown to almost 18 pounds, and it had exceeded 60 pounds by 1900. This is currently in around 100 pounds per annum. At this point, it accounts for a whopping 20% or a quarter of all calories consumed. However, though the sales and use of granulated sugar have stagnated or even decreased, in recent years, the actual consumption has increased as people add less sugar to their food and beverages, more processed foods, beverages and aerated drinks are consumed by people, and these can contain large quantities of secret sugar.

Table 4.1 Country-wise per capita sugar consumption

Country-wise per capita sugar consumption (kg) ^a	2010	2011	2012	2013	2014	2015	2016
India	18.1	16.5	18.1	17.9	18.6	19.8	18.8
China	10.2	10.1	10.4	10.8	11.0	11.3	11.4
Brazil	62.3	62.0	59.6	59.0	54.5	53.9	53.9
USA	30.7	31.1	30.8	30.4	29.5	31.5	31.8
World average	22.5	21.8	22.7	22.8	22.9	22.8	23.0

^aSource: https://www.indiansugar.com/PDFS/World_per_Capita_Consumption_of_Sugar.pdf

There is a growing debate about the intake of sugar and the associated ill health effects, viz. diabetes, obesity, tooth decay, etc. The definitive research is still on, and one must blame the altered lifestyle and not curse the sugar. There is no desirability for the abundance of something, so it is beneficial to increase physical activity and judicious sugar consumption. Although the amount of sugar intake is a personal preference, however, the USDA recommends no more than 10 spoons of added sugar every day. Americans eat twice the amount of sugar and the same amount of HFCS again. The term “added sugar” is frequently used interchangeably with “free sugar”, but sugars and syrups are considered to be added to the food during production and food preparation or at the table and do not contain honey or fruit juices (Johnson et al. 2009). According to the American Heart Association (AHA), the average amount of added sugars that can be consumed in a day by men is 150 calories per day, i.e. 37.5 g or 9 teaspoons, and for women, it is 100 calories per day, i.e. 25 g or 6 teaspoons per day (www.healthline.com > nutrition > how-much-sugar-per-day). Sugar-sweetened beverages comprise the entire range of aerated beverages, fruit drinks and energy drinks containing added sugars. Some of those drinks are sweetened with high-fructose corn syrup, the most common added sweetener in processed foods and beverages, and some are blended with sucrose or fruit juice. HFCS widely used in drinks contains approximately 55% of fructose and 45% of glucose, while saccharose (or table sugar) contains around 50% fructose and 50% glucose. Many fresh sugars are extracted from sugarcane, in addition to sugar. Jaggery is one of them that generally contains 65–85% of sucrose and is also a source of protein, potassium and magnesium. Khandsari is a crystallized granulated sugar which contains 94–98% of sucrose. It is less concentrated, with more calcium retained than sugar (Anderson 1997).

Despite the impression that is often given, sugar isn't toxic, it won't ruin our bones, and if consumed in moderate amounts, it won't do us any harm. However, limiting sugar intake from all sources such as honey and fruit juices would be a smart idea because they too are causing a glycemic shock when they reach the blood rapidly. Furthermore, limiting the amount of sugar that is added to rising processed food and a diet rich in unrefined carbohydrates like whole grains, vegetables, fruits, etc. has been shown to have many health benefits; it is not only responsible for reducing obesity but can also control diabetes, diseases related to the heart, blood pressure problems and even cancer.

4.4 Types of Sweeteners

4.4.1 Natural Sweeteners

Natural sweeteners exist or are produced by nature without any added chemicals or machinery. The only sugars appropriate for eating are wild, non-hybridized, cultivated fruits, natural sugars and starches in living plants, trees, seeds, nuts and roots. Few natural sweeteners include stevia, maple syrup, molasses, coconut sugar,

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date sugar, agave nectar, xylitol, etc. (<http://authoritynutrition.com/4-healthy-natural-sweeteners>).

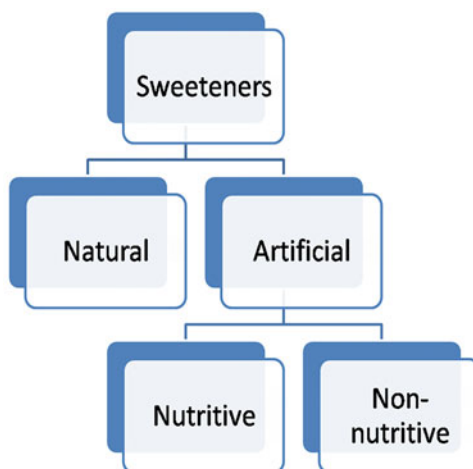
4.4.2 Artificial Sweeteners

Artificial sweeteners are also known as sugar alternatives. These are alternative sweeteners or non-sugar substitutes. They are used in foods and beverages to replace sugar. They can be classified into two huge groups, viz. nutritious sweeteners, which add a certain energy in the form of calories to food, and non-nutritious sweeteners, which are also named as high-intensity sweeteners as they are used in very low amounts, contributing no energy value to food (Layards 2009; American Dietetic Association 2004) (Fig. 4.1).

4.4.3 Nutritive and Non-nutritive Sweeteners

Sucrose or table sugar, fructose, dextrose, lactose and maltose are nutritive sweetener. This means that it provides nutrition, as it contains calories and gives energy in the form of carbohydrates. Honey, agave, high-fructose corn syrup (HFCS) and sugar alcohols like sorbitol, mannitol, xylitol and erythritol are also nutritive sweeteners. A non-nutritive sweetener, though, provides *no* nutrition; according to the USDA, it is defined as zero- or low-calorie alternatives to nutritive sweeteners. Non-nutritive sweeteners are much sweeter than sugar, so only small amount of them is required to sweeten the food products, and they also provide fewer calories per gram than sugar because they are not completely absorbed by our digestive system. A nutritive sweetener adds energy to the diet; however, non-nutritive sweeteners do not add energy. Non-nutritive sweeteners may aid in weight control, and they do not

Fig. 4.1 Classification of sweeteners (Source: Dills 1989)



increase the blood sugar level and are not harmful to teeth; besides, they also decrease calorie content of food and can be used in place of sugar in cooking and baking (American Dietetic Association 2004).

4.5 Several Types of Sweeteners Are Available and Can Be Divided into Six Groups

Nearly all sweetener forms fall under these six groups <http://dictionary.reference.com/browse/artificialsweetener> (Table 4.2).

4.5.1 Sugars

Sugar is a source of carbohydrates and energy that naturally occurs in every fruit and vegetables. It is obtained by the process of photosynthesis in plants where the plants transform solar energy to food for its consumption.

Table sugar is mainly a sucrose molecule which consists of fructose and glucose molecules that give instant energy to our body. The basic function is that as our body cannot absorb disaccharides, it gets broken into glucose and fructose by enzyme sucrose. The absorbed monosaccharides get transported to the liver for processing from where it gets distributed throughout the body. The hormone insulin then facilitates the uptake of glucose into cells, thereby metabolizing energy for immediate use. Sucrose provides energy for build-up and functioning of the cell. Among different foods, including vegetables, fruit, dairy, grains and meat, sugars are naturally present. The most popular are sucrose, glucose, dextrose, fructose, maltose, galactose and trehalose. Sucrose in solution has a sweetness perception rating of 1, and other substances are rated relative to this (Hough 1989; Tombs 1990) (Table 4.3). However, the sugar obtained from sugarcane and sugar beet is commercially available and is used by people in major proportion. It is added to various nutrient-rich foods to enhance taste, flavour, texture and appeal of the food. Sugar may also increase the boiling point and reduce the freezing point in foods (Taneja and Kumari 1989). Sucrose is more rapidly absorbed by the human body as it is more soluble than starch; however, glucose is absorbed at almost double the rate of fructose, and fructose is mainly metabolized in the liver and converted to glucose, glycogen and triglycerides. Different types of white sugars and their alternative name have been given in Table 4.4.

4.5.1.1 Various White Sugar Varieties Are Known for Different Purposes

The details of these speciality white sugars have been discussed in Chaps. 7 and 13.

Table 4.2 Different types of sweeteners that are divided into six groups

1	2	3	4	5	6
Sugars	Sugar alcohols	Natural sweeteners	Zero-calorie natural sweeteners	Modified sugars	Artificial sweeteners
Granulated sugar	Sorbitol	Honey	Stevia	Glucose syrup	Acesulfame potassium
Caster sugar	Mannitol	Maple syrup	Thaumatococcus	Glucose-fructose syrup (HFCS)	Aspartame
Confectioners' sugar	Xylitol	Sorghum syrup	Monellin	Corn sugars (HFCS)	Neotame
Lump sugar and sugar cubes	Maltitol	Palm sugar	Pentadin	High-fructose corn syrup (HFCS)	Sucralose
Coarse grain	Erythritol	Coconut palm sugar	Brazzein	High-maltose corn syrup (HMCS)	Saccharin
Brown sugar	Mogroside V	Agave syrup	Lucama powder	Liquid sugar	Cyclamate
Turbinado sugar	Polyglycitol	Yacon syrup	Miraculin	Amber sugar	Neohesperidin dihydrochalcone
Demerara	Xylitol	Rice syrup	Monatin	Invert sugar	Advantame
Muscovado	Glycerol	Fruit sugars	Glycyrrhizin	Golden syrup	Thaumatococcus
Piloncillo	Lactitol	Monk fruit	Liquorice (glycyrrhizin)	Iso-glucose (HFCS)	DouxMatok sweetener

Table 4.3 Sweetness of various compounds on an equal weight basis with sucrose

Sweetener	Relative sweetness units
Sucrose	1.0
Lactose	0.5
Invert sugar	1.2
Maltose	0.3
Sorbitol	0.5
Mannitol	0.6
D-Glucose	0.6–0.75
Fructose	1.17–1.75
Dextrose	0.7
Cyclamate	26–30
Steviolbioside	40–300
Acesulfame K	150–200
Aspartame	180–300
Sucralose	250–600
Sodium saccharin	300–675
Thaumatococcus	2000
Lugdunane	300,000
Xylitol	0.8–1.1
Maltitol	0.9
Lactulose	0.5
Liquid glucose	0.7

Source: Hough (1989), Tombs (1990), McMurtry (1998), Dermer (1947), Oesten et al. (2007), Guyton et al. (2006), Godswill (2017)

Table 4.4 Different types of white sugars and their alternative name

Types of white sugar	Alternative names
Granulated sugar	Table sugar White sugar
Caster sugar or castor sugar	Superfine sugar Bar sugar Ultrafine sugar
Confectioners' sugar	Powdered sugar Icing sugar (Canada and Great Britain—England) Sucre glace (France)
Lump sugar and sugar cubes	
Coarse grain	Decorating sugar Pearl sugar Coarse sugar Sanding sugar

4.5.2 Brown Sugar

Brown sugar is also made of sucrose with a distinctive brown colour because of the molasses present in it. It may be both unrefined and partially refined soft sugar that

contains sugar crystals along with residual molasses content, or it is produced by the addition of molasses to refined white sugar, which is also called as “molasses sugar”. It can clump because of its moisture content. Different types of brown sugar that are used in cooking, baking and beverage industries include Demerara sugar, turbinado sugar, piloncillo (Mexican sugar), molasses sugar (muscovado), etc. The details of different types of brown sugars have been discussed in Chaps. 7 and 13.

4.5.3 Sugar Alcohols (Polyols)

Sugar alcohols or polyols are prominent, low-calorie sweeteners. These are carbohydrates but not sugars with multiple hydroxyl groups and constitute around 4 calories per gram. They are present naturally in various foods including fruit, vegetables, grains and dairy. Polyols are also termed as sugar replacer; they are produced by hydrogenation of sugars and syrups (<https://www.ynhh.org/services/nutrition/sugar-alcohol.aspx>). They may also act as a laxative and are suitable for diabetes because of their low glycemic index. Sugar alcohols are not widely used in the preparation of home food but are found in many processed foods. The sugar alcohols are commonly used as thickeners and sweeteners in the food industry. In commercial food stuffs, sugar alcohols are widely used in place of table sugar (sucrose), often in conjunction with artificial sweeteners of high intensity (Nutrition 2019), to compensate for their low sweetness. Polyols are partially absorbed by the body and do not cause a sudden increase in blood glucose level, and they are not converted to acids by bacteria in the mouth, so they don't contribute to tooth decay also. The unabsorbed sugar alcohols are partially fermented in the colon and excreted. A number of these are produced using starch as a raw material, among which mannitol, sorbitol, xylitol, lactitol, isomalt, maltitol, etc. are common sugar alcohols (Schiweck et al. 2012).

4.5.3.1 Sorbitol

It is a sugar alcohol having sweet taste. Sorbitol is a hygroscopic, crystalline compound, and due to the absence of aldehyde group, it is a non-reducing, non-fermentable compound and resistant to bacterial action. It is produced by catalytic hydrogenation of glucose or dextrose; however, commercially it is produced by hydrogenation of glucose syrup which is derived by starch hydrolysis. It is found naturally in fruits like apple and pears. It possesses 2.6–3.9 calories per gram as glucose and is converted to fructose in the liver. Sorbitol is harmless to teeth and has a very low glycemic index. It is utilized in the manufacturing of ascorbic acid and different food items like fondants and caramels. It may completely replace sugar in ice creams and chocolates mainly for diabetic people (<http://www.oprah.com/health/sugar-substitutes-Healthy-Natural-Sweetener>).

4.5.3.2 Mannitol

Mannitol is crystalline and non-hygroscopic, possessing almost 40% less sweetness than sucrose. Generally produced by catalytic hydrogenation of glucose and

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mannose, mannitol is used in pharmaceuticals. The Food and Drug Administration (FDA) has designated it as “generally recognized as safe” (GRAS) and approved it in 1971. Mannitol is also found in fruits and can be obtained from corn syrup. They combine well with other ingredients and are absorbed by the body slowly. It is used in crystalline form in sugar-free products, in chewing gums and in most drug components. It is also useful in baking, confectionery and ice creams (Varzakas et al. 2012).

4.5.3.3 Xylitol

Xylitol is a white and crystalline powder found in fruits and vegetables with the sweetness index of 0.8–1.1. It possesses almost 2.4 calories per gram and is non-carcinogenic. In 1963, it was approved by the FDA as a food additive. It is derived from various berries, oats, mushrooms and corn husk. Commercially, it is made from xylan, extracted from hardwoods and corncobs. Sugarcane bagasse also has xylan from which xylitol and xylose may be isolated after hydrogenation. It has no effect on insulin levels and can benefit teeth and is even helpful in reducing acute middle ear infection. Xylitol is useful in baking; however, it is advisable to consume it in moderation; otherwise flatulence and diarrhoea may occur (Ur-Rehman et al. 2015).

4.5.3.4 Maltitol

Maltitol is hygroscopic by nature and carries 0.9 units of sweetness relative to sucrose. Maltitol is produced by hydrolysis and hydrogenation of starch and maltose syrup, respectively. Maltitol helps in moisture retention, so it is used in beverages, in canned fruits and in bakery products. It is also used as a bulking agent for intense sweetness. Lycasin® one of the commercially available maltitol is very hygroscopic and is used as an anti-crystallizing agent in several products (Food Standards Australia New Zealand 2005).

4.5.3.5 Erythritol

Erythritol is a four-carbon sugar that is extracted by reducing erythrose. It is obtained from glucose by fermentation. Erythritol is found in fruits such as pears, melons and grapes and also in foods such as mushrooms and foods that are derived from fermentation, such as wine, soy sauce and cheese. Erythritol is considered to possess antioxidant quality and is readily used in baking (<https://www.webmd.com/diet/what-is-erythritol>).

4.5.3.6 Mogroside V (Esgoside)

The brand name of mogroside is “Nectresse”. It is obtained from a mixture of monk fruit extract and erythritol, a sugar alcohol. The monk fruit extract is also referred to as “Luo Han Guo (Siraitia grosvenorii)”. It is 300 times sweeter than white sugar and is traditionally used as a sweetener in China since 1000 years. The reason behind its sweetness is the five different mogrosides present in the fruit, mainly the esgoside. It is also known as 罗汉果 or a Buddha fruit, and it is similar to stevia, but unlike stevia, it is loaded with antioxidants. Mogroside adds no calories while adding

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a sweet taste. It is the basic ingredient of the new sweetener called Nectresse (Itkin et al. 2016).

4.5.3.7 Polyglycitol

Polyglycitol primarily consists of maltitol with sorbitol, with lower quantities of hydrogenated oligo- and polysaccharides and maltotriitol. It is produced by hydrogenating a mixture of starch hydrolysates composed of glucose, maltose and higher oligomers of glucose. Polyglycitol syrup is used as humectants, i.e. to control the moisture of a substance, and also as a bulking agent. It is readily utilized for modulating the sweet taste of food items and as a zero-calorie sweetener (<http://www.nutrientsreview.com/carbs/hydrogenated-starch-hydrolysates-hsh-polyglycitol-maltitol-syrup.html>).

4.5.3.8 Glycerol

Glycerol, also known as glycerine, is a natural sugar alcohol with a mild sweet taste. It is generally produced by animal or vegetable fat, and it may also be produced by petroleum products. Glycerol has a low glycemic index with almost 4 calories per gram and a sweetness index of 0.4; hence, it is safe for diabetic persons and harmless for teeth. It is mostly utilized as a humectant for keeping the food items moist rather than a sweetener. Glycerol has many medicinal applications like in surgery, lotions and medicated creams and also as a laxative. It also possesses antiseptic quality and is used in toothpaste, cough syrups, etc. It is used in food material for texture and bulk. Although it is recommended safe by CSPI, USA, the bulk consumption of glycerol is not advised. It is also recognized by the FDA and was given a GRAS certificate (<http://www.sugar-and-sweetener-guide.com/glycerol.html>).

4.5.3.9 Lactitol

Lactitol, an artificial polyol, is derived from whey. It was discovered in the year 1920 and is produced by the lactose. It has a low glycemic index with around 2 calories per gram and the sweetness index of 0.4. It is mostly used in the food industry like other sugar alcohols and is useful for diabetes. It is quite useful in biscuits and cookies preparation as it is not hygroscopic and keeps the products crunchy and fresh. Lactitol is found to be heat stable, so it is also useful in cooking and processed food. It is approved by the FDA and should be consumed in moderation due to its laxative properties; however, it is used in medicine for constipation (Miller et al. 2014).

4.5.3.10 Isomalt

Isomalt is also an artificial polyol having low glycemic index with 2 calories per gram and 0.5 sweetness index. It possesses distinctive flavour with no aftertaste and is readily used in baking, confectionery, desserts, chocolates, chewing gums, etc. It is useful for diabetic people. It is not metabolized by the bacteria in the mouth like other sugar alcohols, and so it is not harmful to teeth. Isomalt is not hygroscopic; hence it is very useful as coating substance in confectionery food items like sugar

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candies. It is also a laxative like lactitol, so consumption is recommended in moderation (Grenby 2012).

4.5.4 Natural Sweeteners

Among different sweeteners, honey and maple syrup are the oldest known sweeteners. These contain sugar as well as other beneficial, medicinal and nutritional properties. They tend to have a significantly lower glycemic index than sugar, but still it is advised to consume them in moderation as they can be detrimental in vast quantities for health and teeth. This group of sweetener includes honey, sorghum syrup, coconut, maple syrup, palm sugar, etc.

4.5.4.1 Honey

Honey is a sweet diet produced by bees that use flowers’ nectar. Honey bees produce honey from nectar by the process of regurgitation and store it in honeycombs in the beehive. Honey derives its sweetness from the fructose and glucose and has almost the same relative sweetness as of sugar. Honey possesses antibiotic and antimicrobial properties. Honey also consists of several vitamins like vitamins C and B1, B5, B3 and B2 along with minerals such as magnesium, calcium, sulphur, iron, sodium chloride and zinc. Honey is a mixture of sugars and other compounds consisting of fructose (38.2%), glucose (31.3%), maltose (7.1%), sucrose (1.3%), water (17.2%), higher sugars (1.5%), ash (0.2%) and others (3.2%). Apart from these substances, traces of chrysin, pinobanksin, vitamin C, catalase and pinocembrin are also found in it (Athanasios Labropoulos 2012). However, the composition varies depending on the flower for its production. One hundred grams of honey contains 304 calories and the following nutrients given in Table 4.5.

Consuming honey has many benefits, as it can promote tissue production, collagen and new blood vessels in bruises. It can absorb moisture as well and fight off microbes. Honey’s antibacterial activity may be related to sugars, low humidity, gluconic acid and hydrogen peroxide. Ingestion of pure honey with pollen traces can help to create improved tolerance for local airborne allergens. This has appealing

Table 4.5 Nutritional value of 100 grams of honey

Compound	Quantity
Total fat	0 g
Sodium	4 mg
Potassium	52 mg
Total carbohydrate	82 g
Dietary fibre	0.2 g
Sugar	82 g
Protein	0.3 g
Iron	2%

Source: https://www.nutritionvalue.org/Honey_nutritional_value.html

chemical properties for baking and a distinctive taste that makes this superior to sugar and other sweeteners for certain people. Honey is said to relieve pressure and soothe the throat. Honey is also considered best for symptoms of acute cough and for relief in indigestion, tends to kill harmful bacteria in the gut and protects against gastric ulcers. Honey contains around the same level of fructose as high-fructose corn syrup, depending on different varieties. Honey is used in cooking and baking, as spreads and in various beverages, and it is also used as an adjunct in beer.

Relative difference between honey and white sugar	
Honey	White sugar
Fructose and glucose remain in individual units	Sucrose has glucose and fructose hooked together
One teaspoon of it has 22 calories	One teaspoon of it contains 16 calories
It is more sweeter and denser	It is less sweeter and denser
It has only one processing unit	It is highly processed and requires multi-steps in processing

4.5.4.2 Maple Syrup

Maple syrup is a viscous coloured liquid that originates from the maple tree sap. It has a distinct flavour and typical aromatic sweetness. Maple syrup comprises low calories and higher mineral concentrations such as manganese and zinc. The 100 g of maple syrup contains approximately 260 g of calories. Maple syrup is graded by its colour, flavour and sugar content in it. The grading systems differ between the countries; like in the USA, there are two grades of maple syrup (1) Grade A maple syrup that is light, medium and dark coloured and (2) Grade B that includes syrup which is darker than grade A dark-coloured syrup. The lower darker grade syrups are used in baking and for glazing purposes (Table 4.6).

In cold areas, the maple trees store sugar in their roots. The maple syrup is produced from the sap that rises in the spring, and by tapping or piercing approximately 40-year-old maple trees, the sap is made to run out freely. The collected sap is clear and tasteless having very low content of sugar. It is then boiled to evaporate

Table 4.6 Nutritional content of maple syrup (100 g)

Compound	Quantity
Total fat	0.1 g
Sodium	12 mg
Potassium	212 mg
Total carbohydrate	67 g
Sugar	68 g
Protein	0 g
Calcium	10%
Magnesium	5%

Source: <https://fdc.nal.usda.gov/fdc-app.html#/food-details/169661/nutrients>

water resulting in the formation of syrup having a sugar content of 60%. This maple syrup can be further concentrated to make thicker cuisine, such as maple butter, cream and sugar (Randall 2010). However, the maple sap can be extracted from the trees for only about 6 weeks per season. It is found that 40 L of sap produces almost 1 L of maple syrup, and after refining the syrup, it constitutes approximately 62% of sucrose, 34% of water, 3% of glucose and fructose and 0.5% of acids.

4.5.4.3 Sorghum Syrup

Sorghum syrup is obtained from sorghum canes, mostly in Southern United States. It is one of the most easily affordable sweeteners in the USA. As it is a labour-intensive crop, it was not used much after World War II. Sugarcanes and corns were much cheaper than in the later era, but nowadays, it is gaining back its importance due to its high nutritional value and gluten-free content. The juice obtained from sweet sorghum (*Sorghum bicolor* (L.) Moench) cane is free of impurities and is evaporated in open pans for obtaining concentrated clear, amber colour and mild-flavoured syrup (Bitzer 2002).

It is a highly nutritious, gluten-free syrup and contains many antioxidants, vitamins and trace elements (Table 4.7). Even doctors also recommend it to patients who have a low dose of vitamins in their body. It contains no chemical additives and is pure. Sorghum syrup is also used as an alternative to molasses due to similar taste, and it could be used in providing its unique flavour to recipes where molasses, honey or maple syrup is used. It is used as the main ingredient in many recipes and also used to sweeten baked beans, pancakes, waffles and biscuits.

4.5.4.4 Palm Sugar (Coconut Sugar or Coco Sap Sugar)

Palm sugar is made from the sweet sap extracted from the palmyra palm tree. It is also made from the date palm and sugar date palm; however, nowadays, it is also prepared from the sap of sago and coconut palm tree. Even date sugars are also obtained from palms, but the sugar obtained from this is not very well dissolved in liquids. Palm sugar may vary in colour, i.e. from light golden colour to dark brown. Often palm sugar is sold as “coconut sugar or coco sugar”. Even it is also marketed as “palm sugar” or jaggery. This sugar is mainly found in Asian countries and is a good source of revenue also (Table 4.8).

Coconut sugar is obtained by a two-step process, harvesting or “tapping” the blossoms of a coconut tree; for this, a cut is made on the spadix for the flow of the sap, which is collected in bamboo containers. The collected sap is then made to

Table 4.7 Average composition of sweet sorghum syrup (1 tablespoon)^a

Weight	20 g	Sodium	4 mg
Calories	52	Phosphorus	5 mg
Carbohydrates	13.4 g	Potassium	120 mg
Calcium	30 mg	Riboflavin	0.02 mg
Iron	2.4 mg	Niacin	Trace

Source: <http://www2.ca.uky.edu/agc/pubs/agr/agr123/agr123.htm>

^aThe values vary from sample to sample

Table 4.8 Nutritional content of 0.1 oz of palm sugar

Sugars	3700 mg
Fat	0.0 mg
Carbohydrates	3700 mg

Source: <https://fdc.nal.usda.gov/fdc-app.html#/food-details/169661/nutrients>

transfer into giant woks, and then it is heated at a moderate rate to evaporate the moisture content present in the sap. Sap is chiefly made of water, viz. 80%, and is translucent. With the evaporation of water, the sap begins to thicken as syrupy form, known as “toddy”. Toddy is made to further reduce in the form of block, crystal or soft paste form more often. It is at times kept in toddy form also. The form of coconut sugar is dependent on the moisture availability in toddy (Palm Sugar in Germany 2017).

Based on colour, palm sugar is of two types: (1) dark palm sugar (often called as “jaggery”), which has a distinct aroma and flavour like wine and is mostly used in Indian, Indonesian and some African cuisines, and (2) lighter palm sugar, which is the most common palm sugar used in kitchens in Australia. Palm sugar is loaded with potassium that helps in preventing cramps. It helps in preventing weight gain as it curbs hunger due to the fibres, proteins and carbohydrates that it contains. Compared to other sugars, it contains low calories (288 calories for 1/2 cup vs 387 calories for 1/2 cup). It is generally used in cooking in Southeast Asian recipes. It is also used in certain baking products where it acts as a softener and adds brown colour to the product as it does not melt well. When this sugar is baked and used in foods, it may give brown flecks in food, and also its sweetness tends to tastes like baked products. The glycemic index of sweeteners obtained from sugarcane is higher than coconut sugar. Even maple syrup has high glycemic index compared to coconut sugar.

4.5.4.5 Agave Syrup (Agave Nectar)

This sugar is obtained from the plant agave. It is also known as agave nectar and is obtained from special species of agave plant, viz. *Agave tequilana* (blue agave) and *Agave salmiana*. It is not as sweet as sugarcane, honey or fruit. Most of this sugar is obtained from Mexico and South Africa. In Mexico, it is commonly known as “honey water” or aguamiel. Agave comes in various sizes for obtaining sugar; the most commonly used is weber blue agave for its high carbohydrate content mostly in the form of fructose. Though agave syrup is rich in fructose content, it lacks many essential nutrients and minerals that the plant has (Table 4.9).

The leaves of agave plant are cut off when they are 7–14 years of age, and the juice is extracted and then filtered. Complex polysaccharides present in it are broken down into simple sugars by the process of heating. The main polysaccharide is fructosan or inulin which is mostly converted into fructose. Juice is then concentrated to form syrupy liquid slightly thinner than honey. The colour of syrup varies with the degree of processing of sugar. This process of extraction of agave syrup is applied in *Agave tequilana* species; however, in *A. salmiana*, when

Table 4.9 Nutritional value of 100 g of agave syrup consisting 310 calories

Total fat	0.4 g (0%)
Total carbohydrate 76 g	25%
Dietary fibre 0.2 g	0%
Sugar 68 g	
Protein 0.1 g	0%
Calcium	0%
Iron	0%
Vitamin B12	0%
Magnesium	0%

Source: <https://fdc.nal.usda.gov/fdc-app.html#/food-details/169661/nutrients>

plants start to develop a stalk called quote, it is cut off making a hole in the centre of the plant that gets filled with the liquid known as aguamiel. This liquid which mostly contains polysaccharides is collected daily, and it further breaks into monosaccharides, viz. fructose and dextrose.

Agave syrup has a long shelf-life and it is rich in vitamins E, C and D, calcium, iron, zinc and magnesium. It is helpful for diabetic patients as it has a low glycemic index, and because of its thin consistency, it gets easily dissolved and blends well with other components. It has anti-inflammatory, antimicrobial and immune-boosting system properties and consists of saponins and fructans. Agave syrup possesses inulin that helps in weight loss because of its capability of decreasing the appetite of the person and also because of its low impact over blood sugar level. It also lowers cholesterol and thereby reduces the risk of having cancers and helps in increasing absorbing nutrients like calcium, magnesium and isoflavones.

Agave nectar or agave syrup is used in many ways to enhance a healthy diet. It is used in food items, beverages, pancakes, waffles and cereals as a substitute for sugar. It provides sweetness and easy solubility and even nutrients to the food; it is found that one-quarter cup of agave syrup is equal to one cup of sucrose.

4.5.4.6 Yacon Syrup

Yacon syrup which is a natural sweetener and is from South America is made from yacon tuber. These tubers that look like sweet potato grow in Peru. The prebiotic edible tubers are low in calorie and glycemic index and contain many beneficial properties and soluble fibres that make it suitable for diabetes. The moist tubers with sweet flavour are also called as “apple of the earth” or “Peruvian ground apple”. The roots mainly consist of water; inulin; good carbohydrate, viz. fructooligosaccharides (FOS); and traces of glucose and fructose (Table 4.10). Similar to maple syrup, yacon syrup is usually produced by evaporation process with minimal processing (Lachman et al. 2003). For processing, the tubers are grounded to extract the juice which is then heated to reduce the moisture content. Yacon syrup with caramel taste is often relatable with molasses, sugar or honey in taste; however, it is half as sweet as honey or maple syrup. With a deep and creamy, slightly sweet flavour, it is usually sold in jars such as honey and can be bought online or in speciality food stores. It is

Table 4.10 Nutrient content of 100 mL yacon syrup consisting of 1.5 calories

Sweetness index	0.5
Glycemic index	1
Calories/spoon equivalent	10
Fructooligosaccharides (FOS)	47%
Sucrose	20%
Fructose	7%
Glucose	3%
Protein	1%

Source: <https://fdc.nal.usda.gov/fdc-app.html#/food-details/169661/nutrients>

found quite useful in diabetes and is harmless to teeth. It has a distinct flavour like figs with high antioxidants and potassium content and is medicinally also beneficial. Yacon syrup is usually used as a laxative, and recently it has been also found useful as a weight loss supplement because the roots increase the metabolism of the body and lower blood sugar levels (Genta et al. 2009).

Yacon syrup increases the nutritional value when combined with other foods such as yoghurt. The FOS sugars in yacon are not completely digested. These are regarded as soluble fibre by the body and are passed through the intestine where they provide useful bulk helping to transfer waste into the intestines. They also facilitate the fermentation of beneficial intestinal bacteria. Yacon syrup may readily replace maple syrup or molasses in foods and can be used to sweeten beverages.

4.5.4.7 Rice Syrup (Rice Malt or Brown Rice Syrup)

Rice syrup, a natural sweetener, is commonly known as “rice malt” or “brown rice syrup”. It is highly refined and concentrated made of cooked rice with enzymes. It consists of maltose 45%, glucose 3%, maltotriose 52% and few trace minerals, including magnesium, manganese and zinc (Table 4.11). Commercially it is made by many companies of Asia, the USA and Europe. Rice syrup has a low glycemic index and is less sweet than sugar; however, it should be taken in moderation as excess would be harmful to teeth.

The convention method of obtaining rice syrup is produced by the fermentation process. The process of obtaining it is from either cooked rice or from brown rice flour which is fermented by the addition of barley that is sprouted and contains enzymes that are responsible for the breakdown of long-chain carbohydrates to simple sugars. The fermented liquid is concentrated in a syrup consistency, and then it is filtered and packed in bottles.

Brown rice syrup comprises valuable minerals such as potassium and magnesium and vitamin B. Brown rice syrup has a low glycemic value which means that after intake, it does not cause a sugar rush or a sudden spike in blood sugar. Glucose in rice syrup is absorbed rapidly; however, it takes approximately 2–3 h to metabolize the soluble carbohydrates present in it and release energy. This process results in a constant supply of energy for a long time rather than immediately (Shaw and Sheu 1992). As this sweetener, unlike refined white sugar, is completely natural and full of

Table 4.11 Nutritional value of 100 mL rice syrup (200.8 calories)

Protein	10.3 g
Total fat	3.9 g
Saturated fat	3.9 g
Trans fat	0 g
Polysaturated fat	0 g
Monounsaturated fat	0 g
Cholesterol	0 g
Total carbohydrate	65.4 g
Sugars	55.3 g
Maltose/fructose	25 509.1 mg
Glucose/sucrose	3428.9 mg
Dietary fibre	6.8 g
Sodium	11.8 mg
Potassium	419.3 mg
Calcium	16 mg
Magnesium	164.5 mg
Manganese	6.3 g
Phosphorus	49.2 mg
Iron	2.8 mg
Copper	3.6 mg
Zinc	0.2 mg
Vitamin B6	9.2 mg
Niacin	0.2 mg
Thiamine	0.6 mg
Riboflavin	1.02 mg

Source: <http://convert-to.com/572/organic-brown-rice-syrup-conversion-with-nutritional-facts.html>

minor nutrients, it is very useful in making nutritious protein bars, croissants, desserts, etc. It is also effective in relieving exhaustion and calming muscles, nerves and blood vessels, thus relieving the complications of asthma, migraine headaches, muscle pain and soreness. The potassium and sodium element in it helps to regulate blood pressure and decreases the retention of water. The iron present in syrup helps in cellular-level respiration by synthesizing haemoglobin that tends to bring oxygen to cells. The manganese, and vitamin B present in rice syrup, is an essential cofactor in many enzymatic reactions in the body, especially in the production of energy and antioxidants defences. It may be used in moderation in place of white sugar.

4.5.4.8 Fruit Sugars (Crystalline Sugars)

Fruit sugars or fructose is just a monosaccharide that is found in many plants and is often linked to glucose that forms sucrose. It was discovered in 1847 by French chemist, [Augustin-Pierre Dubrunfaut](#). Commercially fructose is often obtained from well-known sources of sugars, viz. sugarcane, sugar beets and corn. Along with glucose and [galactose](#), it is also one of the dietary monosaccharides (Table 4.12).

Table 4.12 The amount of sugars present in 3 oz of raw fruits that consist of different calorie intake

Fruit (raw) (3 oz)	Sugar total (g)	Total calorie
Strawberries	4	27
Papaya	5	33
Watermelon	5.3	26
Grapefruit	5.9	27
Cantaloupe	6.7	29
Nectarines	6.7	37
Peaches	7.1	33
Kiwis	7.6	52
Guavas	7.6	58
Apricots	7.9	41
Oranges	8	40
Pears	8.3	49
Plums	8.4	39
Pineapple	8.4	43
Blueberries	8.5	48
Apples	8.8	44
Tangerines	9	45
Bananas	10.4	76
Cherries	10.9	54
Pomegranates	11.6	71
Mangoes	12.6	55
Grapes	13.2	59
Figs	13.8	63

Source: <http://www.fitsugar.com/Sugar-Content-Fruit-20134844>

Commercially there are three forms of fruit sugars: (1) crystalline fructose (CF), which is a monosaccharide of high purity; (2) high-fructose syrup (HFC), which consists of a mixture of two monosaccharide sugars, viz. glucose and fructose; and (3) sucrose, which consists of one molecule of glucose which is covalently linked to one molecule of fructose. The major advantage of fruit sugars is that they get directly absorbed in our bloodstream during digestion. Fruit sugars are used as a taste enhancer in foods and drinks and browning of some food items like baked goods; used in dry mixes such as flavoured gelatin, pudding desserts and powdered drinks; and in foods and drinks for palatability.

4.5.4.9 Monk Fruit (Luo Han Kuo)

Monk fruit, from gourd family, is an extremely sweet fruit, grown in China, and is also known as Luo Han Kuo or Luo Han Guo (ARS 2017; Itkin et al. 2016). The sugar which is known as “mogroside” substance extracted from this fruit is almost 200 times sweeter than sucrose. It has zero calories and glycemic index, does not increase the blood sugar levels and is approved by the FDA. It is used as a flavour enhancer in food products and different beverages. It is also used in relieving

allergies, increasing immunity and controlling diabetes due to its potential medicinal properties (Kinghorn and Soejarto 2002).

4.5.5 Zero-Calorie Sweeteners

These are sweeteners with few to no calories in them, and they have emerged as a safer alternative to artificial sweeteners only in recent years. They have a zero glycemic index and are harmless to the bones. It may have a similar aftertaste to artificial sweeteners. Zero-calorie organic sweeteners include stevia, thaumatin, monellin, brazzein, pentadin, lucama powder, etc.

4.5.5.1 Stevia (*Stevia rebaudiana* Bertoni)

Stevia extract is obtained from the renowned plant, stevia, native to South America. It is used there for centuries and even in Japan for the past 30 years; now it is also grown in many tropical and subtropical countries including China (Petruzzello 2017). It is a low-calorie natural sweetener with zero glycemic index and was discovered in the year 1899 by M. S. Bertoni. Stevia sweetness is derived from the two compounds present in its leaves, viz. steviosides and rebaudiosides, and it is almost 300 times sweeter than white sugar (Abdullateef and Osman 2012). The sweetness is extracted from the leaves with the help of ethanol, and it is sold in the form of powdered leaves and as concentrated stevioside. Its brand name is “Truvia” and “PureVia” which contains rebaudiosides A along with erythritol. It is also called Rebiana, which has one beta-D-glucose molecule replacing the hydrogen atom at the bottom and three beta-D-glucose chains replacing hydrogen at the top, while stevioside has one beta-D-glucose replacing the top hydrogen site. Researchers have revealed that it is useful for lowering blood pressure and blood sugar levels and is not harmful to teeth as it does not contain any carbohydrates. It is considered to be safe for pregnant women and is useful in baking and cooking because of its stability towards heat. Stevia is also quite useful in processed foods and diet beverages (Misra et al. 2011).

4.5.5.2 Thaumatin (*Thaumatococcus daniellii* Bennett)

Thaumatococcus, a natural protein sweetener, is extracted from the katemfe fruit which is a native of Sudan and West Africa. It is a low-calorie sweetener possessing 2000 times more sweetness than sugar with zero glycemic index (Green 1999). Thaumatin is sold under the brand name “Talin”, and the protein present in it basically acts as flavour enhancer and modifier rather than imparting sweetness to the products. The liquorice aftertaste of thaumatin is its key feature that makes it different from usual sugar. It is soluble in water and aqueous alcohol and does not promote tooth decay. Thaumatin is used in beverages, and because of its liquorice taste and delayed sweetness, it is used as a partial sweetener and often used in combination with other sweeteners. It is readily water-soluble and stable in heating and acidic conditions, and its sweetness is built quite slowly. Thaumatin is considered to be safe for consumption and is quite useful for diabetic people. However, earlier in a

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few products like chewing gum, thaumatin powder was found to cause allergies, but when the powder was replaced by liquid form of it, the allergic symptoms were found to be eradicated. Human body may metabolize thaumatin like other protein ingredients. It was found that thaumatin flavour and sweetness are improved when it is used in combination with stevia, and it works as a flavour enhancer of milk products and sodiumless food items.

4.5.5.3 Monellin (*Dioscoreophyllum cumminsii*)

Monellin is a natural sweet [protein](#), which is 800–1500 times sweeter than 7% sugar solution. It was discovered in 1969 from the fruit of [serendipity berry](#) (*Dioscoreophyllum cumminsii*) which is native of Central and West Africa (Morris et al. 1973). This fruit was recorded as the sweetest substance known by Guinness Book Records in 1972. Monellin was first reported as a [carbohydrate](#); however, in 1972, it was extracted and characterized as protein by [Monell Chemical Senses Center](#) in [Philadelphia](#), USA. Monellin contains 4 calories per gram with zero glycemic index, and it is suitable for diabetics. Monellin is readily soluble in water due to its hydrophilic properties, so it can be useful for [sweetening](#) some foods and drinks, but it is found to lose its flavour in carbonated drinks and is not suitable for such beverages. Also, it is not stable at high temperatures and gets denatured, so it is not utilized in processed foods as well. However, a very small amount of monellin is required to sweeten any food item, and it is metabolized by the human body like protein ingredients (Gelardi and O'Brien Nabors 1991). It may be used as protein tabletop sweetener, especially by diabetics, and may also be used in certain pharmaceutical products.

4.5.5.4 Pentadin (*Pentadiplandra brazzeana* Baillon)

Pentadin, a naturally [sweet-tasting protein](#), discovered in 1989, is extracted from the fruits of [oubli](#) (*Pentadiplandra brazzeana* Baillon) (van der Wel et al. 1989). The fruit is mostly grown in tropical countries like Africa and is a climbing shrub. Earlier it was consumed by the apes only; however, later the berries of the shrub were discovered to be incredibly sweet by the locals (Ming and Hellekant 1994). The fruit was named “j’oublie” which means “I forget” in French by the natives as it was believed that the taste of the fruit helps nursing infants forget their mothers’ milk. Pentadin is reported to be 500 times sweeter than [sucrose](#), and it contains around 4 calories per gram and zero glycemic index. It may be beneficial for diabetic people, in food items and in pharmaceuticals; however, its properties still need to be evaluated.

4.5.5.5 Brazzein (*Pentadiplandra brazzeana* Baillon)

Similar to pentadin, brazzein, a new protein sweetener, is also isolated from the fruits of oubli. Brazzein is found to be highly sweet and is 500–2000 times sweeter than sucrose (Faus and Sisniega 2004). It contains 4 calories per gram and zero glycemic index. It has a distinctive sweet flavour with no bitter aftertaste. The structure of brazzein consists of 54 amino acids arranged in 1 alpha-helix and 3 strands of anti-parallel beta-sheets. It is found to be heat (Birch 2000) and pH stable (Ming and

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Hellekant 1994) and can be used in different cuisines in cooking and in processed food also. Although brazzein is awaiting approval in the USA and is not yet approved by EU, it would be more acceptable to consumers and easier to gain regulatory approval because of its potential applications and it has no side effects.

4.5.5.6 Lucama Powder (*Pouteria lucuma*)

Lucama powder is a new superfood that is coming in the market nowadays. It is sweet as refined white sugar and has fragrance. Lucama powder is obtained from the tree named *Pouteria obovata* or *Lucuma obovata* that is found in Chile, Peru and Ecuador. Lucama tree is grown in cool weather and is considered to be drought resistant that grows up to a height of 25–50 feet. The fruit obtained from this tree is yellowish green in colour and is egg-shaped with a dry, starchy, yellow-orange flesh. It tastes maple-nutty or caramel to pumpkin-like and consists of numerous nutrients (iron, high level of carotene, vitamin B3 niacin, calcium, phosphorus, magnesium and trace elements) that benefit our body (Table 4.13). Traditionally, it is named as “Gold of the Incas” because in ancient times of Incas, it was valued like gold. Nowadays, it is used in flavouring ice creams, often over chocolate or vanilla flavoured. The fruit was regarded as a symbol of fertility and creation (<https://www.healthline.com/nutrition/lucuma-benefits>).

The lucuma powder is produced by dehydrating the pulp of the lucuma fruit, and the powder is marketed as a flavour enhancer. It is considered to be great for breastfeeding women as well as diabetic patients due to low sugar content. It acts as a sweetener but does not increase the blood sugar levels compared to others that just increase calories. For centuries (South America), lucuma powder is known for its medicinal properties. It has been used as an anti-inflammatory on wounds for healing, in skin ageing and even in skin repair. It has low glycemic value that is boon for the persons who need low sugar intake. This sweetener is generally used for baking purposes and in fortification of nutrients in cuisines. Lucuma powder is also useful in preparing ice cream, nutritional beverages, yoghurt products, pudding, etc., because it helps in combining and emulsifying fats and oils with sugars and available polysaccharides. Due to its smoothness, it blends well with other components (creamy-textured raw fats, nuts and seeds) and also tastes delicious with almond milks and nut milk recipes.

Table 4.13 Nutritional value of 100 g of lucama powder (329 calories) and the following nutrients

Total fat	2.4 g
Total carbohydrate	87 g
Dietary fibre	2.3 g
Sugars	13 g
Protein	4 g
Phosphorus	186 mg
Calcium	92 mg
Iron	14%

Source: <https://www.healthline.com/nutrition/lucuma-benefits>

4.5.5.7 Glycyrrhizin (Liquorice)

Liquorice or glycyrrhizin is a natural sweetener with zero calorie and glycemic index and is extracted from liquorice root. The roots basically contain glycyrrhetic acid and glucuronic acid. It has a strong flavour and taste similar to stevia. Glycyrrhizin is generally utilized in candies, in cough syrups, in ulcer medicines and not as a sweetener alone. It may be consumed in moderation; however, the glycyrrhizic acid present in it also act as an anti-inflammatory, antiviral, immune-increasing substance, and in Japan, it is used to reduce the risk of liver cancer and in chronic hepatitis (Fiore et al. 2008).

4.5.6 Modified Sugars

4.5.6.1 Starch-Based Modified Sugars

These are generally starch-based sugars produced by enzymatic transformation of starch. The starch molecule contains a large chain of glucose units. Glucose has been important in the food industry since the nineteenth century, when Europeans tried to replace cane sugar products which were in short supply. In the year 1811, Kirchoff, a German scientist, discovered the sweet property of starch (Hull 2011). Later in the 1960s, enzymatic hydrolysis of starch was carried out to extract its sweetness. Starch-based sugars meet the demand for sweetening mixtures and provide additional features for many sectors such as beverages, confectionery, dairy products, etc. that contribute to the final product's texture, colour stability and flavour while remaining economical. These starch-based sugars have a high glycemic index. They are used in food production or food processing. Modified sugars includes glucose syrups, refiner's syrup, high-fructose corn syrup (HFCS), caramel, liquid sugar, invert sugar, golden syrup, etc.

Glucose Syrup

Glucose syrup is a processed, condensed, aqueous solution of glucose, maltose and glucose oligomers obtained by regulated partial edible starch hydrolysis (Hull 2010). It is obtained by either glucose conversion or by edible inulin hydrolysis and contains no fructose. Glucose syrups are mainly used for their anti-crystallizing function in the confectionery, while they are particularly used for their sweetening power in brewing. Glucose syrups can adapt to a vast range of products, each developing different properties, just as with the starch from which they originate. It is available in liquid, solid and transparent form which is quite similar to honey. In glucose syrup, the glucose molecule is the same as in sucrose, or lactose. Various methods are used during processing to break down the starch, to varying degrees, to produce a broad variety of glucose syrups, both providing different useful properties. Such syrups contain both free dextrose and varying lengths of glucose chains. For example, glucose syrup can be added in a cake for a luxuriant texture, while white sugar adds sweetness. Also, glucose syrups avoid the drying of biscuits, keep cakes moist, avoid the crystallization (Knehr 2008) of sugar in sweets and jams and prevent water crystallization in ice creams.

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Corn Sugars (High-Fructose Syrups/Isoglucose/Glucose-Fructose Syrup)

Corn syrup was basically invented in 1950, but commercially it was produced in the 1970s. High-fructose corn syrup (HFCS) is prepared with varying proportions of glucose and fructose by the acid hydrolysis of corn starch (European Starch Association 2013). The viscosity of the syrup is dependent on the number of carbohydrate molecules that are present in it. The most common type of HFCS consists of around 55% of fructose and 42% of glucose molecules (Table 4.14). In a few countries, HFCS is also referred to as isoglucose or glucose-fructose syrup. It consists of almost 4 calories per gram with 58 glycemic index and sweetness index 1.2. The thick viscosity of corn syrups imparts a chewy texture to foods, and its acidic nature makes it useful for baking. Light corn syrup consists of 75% fructose and glucose and has the sweetness similar to sugar; however, dark corn syrup is a combination of corn syrup and refiner’s syrup and is used for colour and flavour in baked products. In other food industries, it has multiple uses as it is found to be an economic sweetener. It may also be utilized in stabilizing and increasing the shelf-life of processed foods. Glucose-fructose syrup comes in liquid form which makes mixing with other products like beverages easier than solid sugars. It may provide texture, volume, flavour, gloss, enhanced stability and longer shelf-life for the products it adds to.

Earlier HFCS was regarded quite similar to white cane sugar. However, the cane sugar constitutes 50% each of glucose and fructose linked with glycosidic bond. These bonds are broken during digestion by hydrolysis into its component parts. Usually the glucose molecule reduces appetite, and fructose molecule increases it. In HFCS, the glucose and fructose are not bonded and present in free states, and in most of the beverages that contain HFCS, the fructose was found to be 55%, whereas glucose was 42% only with traces of other sugars (US Food and Drug Administration 2018); however, the 13% unbounded fructose may affect the body in a negative way like overeating or increased triglyceride level in blood, obesity, etc. So, although earlier it was thought that HFCS may prove to be a promising alternative of white sugar, later it was realized that it is harmful to health than ordinary sugar (Hull 2010).

Table 4.14 Nutritional value of 100 g of corn sugars consisting of 286 calories

Substance	Quantity
Total fat	0 g (0%)
Sodium	155 mg (6%)
Potassium	44 mg (1%)
Total carbohydrate	78 g (26%)
Sugar	78 g
Magnesium	2%
Iron	2%
Calcium	1%

Source: <https://fdc.nal.usda.gov/fdc-app.html#/food-details/169661/nutrients>

High-Maltose Corn Syrup

High-maltose corn syrup is produced from corn starch by acid hydrolysis, and it consists of glucose and maltose. It is found to be better than HFCS as it contains no fructose. It contains around 4 calories per gram, 0.5 sweetness index and hundred glycemic index. HMCS is very sweet and is utilized basically as a food preservative. It is also found to be useful in baking and brewing industries and is used in frozen foods due to its low freezing point (Hui 2006; Hull 2010).

4.5.6.2 Other Modified Sugars

Liquid Sugar

Liquid sugar is a product made by dissolving refined granulated sugar in water. The most common liquid sugar contains 65–67 g of sucrose dissolved in water. Commercially, this sort of sugar is available as name of Indiana liquid sugar, is a premium pure solution that is easy to handle and is even an alternative of granulated sugars. It is carefully being produced with the finest quality of sugar that provides consistent flavour and low colour. Liquid sugar lowers the process steps in production and is the best-suited product for foods containing water. These sugars are even used in jams, marmalades, fruit juices, grocery products and marinades. It is also used with other components like primarily corn syrup and liquid sweeteners and as a blending component for specific applications. It is even used in many beverages and is considered to be free of flocculants. Non-food applications also require liquid sugar as substrate, particularly in industrial fermentation. Liquid sugars are also readily utilized in the pharmaceutical industry (<http://www.boettger-zucker.com/en/liquid-sugar>). Table 4.15 shows the nutritional value of 100 g of 67% liquid sugar.

Amber Sugar

Amber sugars or amber rock sugars are sugar in its purest form, and they are made from the sugar solution by crystallization process. It is darker in colour compared to other natural sugars and is used where brown sugar is desired. It is an ideal sweetener, and when replaced by white sugar, it adds not only sweet taste, but also it does not affect the profile of the tea. In Europe, its commercial product is named as rocky amber, and it has been used for a long time as a sweetener as it provides a cordial taste to coffee also.

Table 4.15 Nutritional value of 100 g of liquid sugar consisting of 260 calories

Total fat	0.1 g
Sodium	12 mg
Potassium	212 mg
Total carbohydrate	67 g
Sugar	67 g
Calcium	10%
Magnesium	5%

Source: <https://fdc.nal.usda.gov/fdc-app.html#/food-details/169661/nutrients>

Invert Sugar

Invert sugar is the product obtained by breakdown of sucrose to glucose and fructose. Commercially invert sugar is the liquid mixture containing half amount of glucose and half amount of fructose in equal volumes. Invert sugars are sweeter than other sugars due to the presence of fructose in it. It is used in confectioneries for preparation of various jellies, cakes, ice creams, etc. It has the consistency of honey and corn syrup and helps in controlling crystallization. Certain baked goods contain invert sugar for increasing tenderness and moisture and even aroma intensification (Schiweck et al. 2007). It is frequently used as sweetener ingredient in the food industry.

Golden Syrup

Golden syrup is made from both sugarcane and sugar beet and is widely available across the world. It was discovered by Abram Lyle in 1883 as a sugarcane by-product. It has a thick consistency, with a unique flavour, and is found to be quite good for cooking and baking purpose. This syrup is quite similar to honey in appearance and is generally used as its substitute. Golden syrup consists of almost 45% sucrose and 55% glucose and fructose. It carries almost 4 calories per gram, 65 glycemic index and 1.5 sweetness index. Golden syrup should be consumed in moderation as bulk consumption may lead to obesity and tooth problem (Varzakas et al. 2012; Kent 2013).

4.5.7 Artificial Sweeteners

Artificial sweeteners have been in use for over 120 years in both America and Europe. These sweeteners have zero calories and are synthesized chemically from organic compounds. These organic compounds may be natural or artificial. They have a glycemic index of zero and are harmless to the teeth. Artificial sweeteners are usually recommended in type 2 diabetes; unlike sugar, they do not raise blood sugar levels because they are not carbohydrates. The artificial sweeteners are generally used as tabletop sweeteners, in hot and cold beverages and in baked products, diabetic foods, bulking agents, etc. The most popular artificial sweeteners are acesulfame K, cyclamate, aspartate, sucralose, saccharin and neotame.

4.5.7.1 Acesulfame Potassium (Brand Name: Sunett and Sweet One)

Acesulfame K (ACE-K) is a general-purpose sweetener and is crystalline. In the 1960s, it was first discovered and is found to be 180–200 times sweeter than sugar. It is usually marketed under the brand name “Sunett” or “Sunette and Sweet One”. It is approved as a sweetener in 2002 by the FDA (UK: Food Standards Agency 2012). It contains zero calories and is even approved for consumption by pregnant women in moderate amounts. It is a non-nutritive sweetener. It passes through the body without being digested. ACE-K is useful in baking and does not initiate or help cancer cells in any way and even does not increase the blood sugar level. It is used in chewing gums, low-calorie syrups, instant gelatin or pudding desserts, etc.

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4.5.7.2 Aspartame (Brand Name: NutraSweet, Equal, Spoonful and Equal-Measure)

Aspartame, discovered in the year 1965, was approved by the FDA for utilization in food and beverages in 1996. FDA has set the daily intake of this sugar as 50 mg/kg of body weight (equivalent to 12 oz or 4 cans of diet soda per day). Aspartame is made from two amino acids (the building blocks of protein): L-phenylalanine and L-aspartic acid. Its brand name is “NutraSweet and Equal”. It is a methyl ester of the dipeptide of amino acids aspartic and phenylalanine. It has 4 calories per gram and is used as a tabletop sweetener. It is 80–200 times sweeter than regular sugar. It has no connection with cancer and is also approved for consumption by pregnant women. However, it is restricted in children as it is found that high levels cause alteration in brain activity. People may have seen to have sensitivity towards this sugar and may complain of headache, dizziness, mood changes or skin reactions after its intake. It is unsafe for phenylketonuria patients, and it shouldn't be used in baking because it loses sweetness at high temperatures (Magnuson et al. 2007).

4.5.7.3 Neotame

It has been approved by the FDA in 2002. It is a chemical derivative of aspartame and is 7000–13,000 times sweeter than white sugars (Nutrition 2019). It consists of zero calorie and is approved for consumption by pregnant women and is even safe for diabetic patients as it shows no effect on insulin levels and also no link between it and cancer. It is readily metabolized and eliminated by the body by normal biological process. Neotame is quite similar to aspartame, but a free amine group present in neotame prevents the metabolism to produce phenylalanine that may cause tolerance problem in some people. However, the minor amount of methanol that is generated by the metabolism of neotame is eliminated from the body by urine and faeces within 72 h. It is used in foods and beverages, including chewing gums and carbonated soft drinks, as a tabletop sweetener and in frozen desserts, puddings, yoghurt, baked goods and candies. It is also used in soy-based fortified products.

4.5.7.4 Sucralose (Brand Name: Splenda, Sukrana, SucraPlus, Candys, Cukren and Nevella)

Sucralose, an intense sweetener produced by substituting hydroxyl group of sucrose by chlorine, was discovered in 1976 and is approved by the FDA. It is 600 times sweeter than white sugars and contains maltodextrin for bulk formation. Its brand name is Splenda (Friedman 1998). Sucralose does not hydrolyse and is non-toxic. FDA has concluded that it has no toxic or carcinogenic effects and even does not possess any reproductive or neurological risks to people. It is poorly absorbed in humans, and most of the sucralose consumed is excreted in the faeces as such. Research have shown that it is safe for both healthy and diabetic people. Commercial product consists of a mixture of dextrose, sucralose and maltodextrin. Ten grams of it consists of 8.03 g of dextrose and 0.96 g of starch (Filipic 2004). It is stable at hot and cold temperatures and can be used in cold and hot drinks. Sucralose is useful in baking, carbonated beverages, dry milk products, frozen foods, fruit spreads and syrups.

4.5.7.5 Saccharin (Brand Name: Sweet’N Low, Sweet Twin, Necta Sweet and Equal)

Saccharin, discovered in 1879, is the oldest known artificial sweetener (Remsen and Fahlberg 1880). FDA had earlier proposed a ban on this sugar but this ban was dropped out in the year 2000 (<https://www.drugs.com/inactive/saccharin-172.html>). It is slightly bitter and has a metallic aftertaste; hence it is usually combined with other sweeteners for consumption. It is a molecule made from petroleum and is 300 times sweeter than regular sugar. It is marketed under the brand name “Sweet’N Low”. It is mostly consumed during World War I due to a shortage in sugars. Commercial product of saccharin consists of 3.6% soluble saccharin and low amounts of anti-caking agents (Chattopadhyay et al. 2014). It is not recommended for use by pregnant women. Saccharin is regarded as disadvantageous for infants and children and is used to sweeten drinks, candies, medicines, toothpastes, mouthwashes, salad dressing, etc. It is not useful in baking as it is unstable when heated.

4.5.7.6 Cyclamate

Cyclamate is 30–50 times much sweeter than white sugars. Its brand name is “Sucaryl and Sugar Twin”. Cyclamate was approved by the FDA in 1958 but was banned in the year 1969. It possesses no calories and is non-carcinogenic. It is salt of sodium or calcium, i.e. cyclohexanesulfamic acid. Generally cyclamate and saccharin are combined in the ratio of 10:1 and produce most desirable sweetness, where cyclamate masks the aftertaste of saccharin. It is useful as a flavour enhancer and is used in many pharmaceuticals and toiletries (Smith and Hong-Shum 2008).

4.5.7.7 Neohesperidin Dihydrochalcone (NHDC)

NHDC is an artificial sweetener and is derived from neohesperidine, which is extracted from bitter orange fruit (*Citrus aurantium*). It may also be obtained by catalytic hydrogenation of naringin with the help of a base like potassium hydroxide. NHDC is 1500–1800 times sweeter than sucrose. It is heat stable and, thus, it may be used in pasteurized foods. It is a flavour enhancer and does not promote tooth decay. It may be used in candies, ice creams, yoghurt products, chewing gums, desserts and pharmaceutical products (Winnig et al. 2007).

4.5.7.8 Advantame

During the year 2014, the FDA has approved a new sweetener named “advantame”. It is regarded as a general-purpose sweetener, a flavour modifier and enhancer in many food items. Advantame was prepared by a Japanese company, Ajinomoto, and it is a combination of artificial substances aspartame and vanillin. It is found to be 20,000 times sweeter than sucrose (EUR-Lex 2019).

4.5.7.9 Steviol Glycosides: Reb M and Reb D (EverSweet™)

In the year 2015, a company in Minneapolis, Cargill, developed a new sweetener by the fermentation process. It was produced by the fermentation of steviol glycosides, Reb M and Reb D, with the help of yeast. These molecules are naturally present in

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stevia and are responsible for the sweet taste of stevia leaves. This was discovered by the company which led them ultimately to produce these molecules artificially in the lab. The product was named “EverSweet”, and molecularly it was quite similar to stevia; however, it does not grow like a plant; rather it is produced in the lab. EverSweet with zero calories has a good taste, and the sweetness is almost similar to stevia. It may be used in candies, as flavour enhancer in yoghurt, to sweeten the carbonated soft drinks and in flavoured waters, powdered drink sticks, energy drinks, chocolate milks, coffee, etc. EverSweet carries more sweetness intensity with improved quality, and it does not have any aftertaste effect in moderate costs (<https://www.cargill.com/food-bev/na/eversweet-sweetener>).

4.5.7.10 DouxMatok Sweetener

A company in Israel named DouxMatok has developed a novel sugar. This sweetener is produced by coating small organic food-grade particles with sucrose (ordinary sugar) to produce a product that tastes just like sugar, but with half the calories. The organic food particle used as a base is approved, and it is in use in the food industry. This semi-artificial sugar may be used in the beverage industry, chocolates, ice creams and candies and also as a tabletop sweetener. Constituting half the calories compared to conventional sugar, this new approach of delivering 100% taste with 50% of the substance by tricking the taste buds holds huge promise. DouxMatok sweetener tastes good and possesses almost 2 calories per gram with 32.5 glycemic index and sweetness index 1; however, this information about this sweetener is based on preliminary knowledge and may be revised based on more studies regarding this product (<https://www.douxmatok.com>).

Table 4.16 gives an overview of the different types of artificial sweeteners, their relative sweetness to sucrose and their various uses.

Artificial sweeteners are gaining popularity nowadays due to zero-calorie content; however, because of consuming less calories, people may end up having a high dose of other food items and, as a result, may gain weight. Although most of the artificial sweeteners are not harmful, they must be consumed in moderation.

4.6 Calories, Sweetness Index and Glycemic Index of Sweeteners

Tables 4.17, 4.18, 4.19, 4.20, 4.21, and 4.22 shows the calories per gram, sweetness compared to sugar and the glycemic index of different types of sweeteners. The sweetener values are measured using dry weight.

4.7 Conclusion

Over the years, there is a shift in direct and indirect consumption of sugar as reflected from the consumption of sugars in many countries. There is a visible shift in the common consumer preferences with respect to the quality and consumption keeping

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Table 4.16 Different types of artificial sweeteners, their relative sweetness to sucrose and utilization

Chemical name	Brand name	Sweetness relative to sucrose	Applications
Acesulfame	Sweet one [®] Sunett [®]	≥200	Flavour enhancer, candies, baked goods, frozen desserts, beverages, dessert mixes and tabletop sweeteners
Aspartame	Equal NutraSweet NutraTaste	≥180–200	Tabletop sweetener, foods and beverages, yoghurt, medicines
Neotame	None	≥8000–13,000	All-purpose sweetener, cooking and baking, baked goods, beverages, candies, chewing gum, dairy products, frozen desserts, puddings, yoghurt
Saccharin	Sweet'N low, sweet twin, equal	≥300–700	Carbonated diet drinks; candies, jams, jellies and cookies; medicines, as a sugar substitute in coffee and baking
Sucralose	Splenda, Sukrana and Nevella	≥600	Candy, breakfast bars and soft drinks, as a replacement for, or in combination with, other artificial or natural sweeteners
Sodium cyclamate	Sucaryl [®]	≥30–140	Food and beverage industries, cosmetics, as sweetener in food production
Thaumatococin	Talin	≥1500–2000	Sweetener, flavour enhancer and flavour modifier
Neohesperidin dihydrochalcone (NHDC)	Golden Health	≥1500–2000	Flavour enhancer, pharmaceutical, beverages, savoury foods, toothpaste, mouthwash and condiments
Advantame	–	≥20000	Taste enhancer, foods and beverages
Steviol glycosides, Reb M and Reb D	EverSweet	≥100	Candies, flavour enhancer in yoghurt, to sweeten the carbonated soft drinks, flavoured waters, powdered drink sticks, energy drinks, chocolate milks, coffee

Source: <http://www.sugar-and-sweetener-guide.com/sweetener-values.html>

Table 4.17 Sweetness index, glycemic index and calories per gram of different sugars

S. no.	Name	Calories/gram	Sweetness index	Glycemic index	Calories/spoon equiv
1	Fructose	4	1.7	23	9
2	Sucrose	4	1	65	16
3	Glucose	4	0.75	100	21
4	Dextrose	4	0.75	100	21
5	Trehalose	4	0.45	70	36
6	Galactose	4	0.3	23	53
7	Maltose	4	0.3	105	53
8	Lactose	4	0.15	45	107

Source: <http://www.sugar-and-sweetener-guide.com/sweetener-values.html>

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Table 4.18 Calories per gram, sweetness relative to sugar and glycemic index of sugar alcohols

S. no.	Name	Calories/ gram	Sweetness index	Glycemic index	Calories/spoon equiv
1	Erythritol	0.2	0.65	1	1
2	Xylitol	2.4	1.00	12	10
3	Maltitol	2.4	0.90	35	11
4	Mannitol	1.6	0.50	2	13
5	Isomalt	2.1	0.50	2	17
6	Sorbitol	2.6	0.55	4	19
7	Lactitol	2.0	0.40	3	20

Source: <http://www.sugar-and-sweetener-guide.com/sweetener-values.html>

Table 4.19 Calories per gram, sweetness relative to sugar and glycemic index of natural calorie sweeteners

S. no.	Name	Calories/ gram	Sweetness index	Glycemic index	Calories/spoon equiv
1	Honey	4	1.1	50	14
2	Maple syrup	4	1	54	15
3	Coconut palm sugar	4	1	35	15
4	Sorghum syrup	4	1	50	15

Source: <http://www.sugar-and-sweetener-guide.com/sweetener-values.html>

Table 4.20 Calories per gram, sweetness relative to sugar and glycemic index of natural zero-calorie sweeteners

S. no.	Name	Calories/ gram	Sweetness index	Glycemic index	Calories/spoon equiv
1	Thaumatococcus	4	2000	0	0
2	Monellin	4	1500	0	0
3	Brazzein	4	1000	0	0
4	Pentadin	4	500	0	0
5	Luo Han Guo	0	300	0	0
6	Stevia	0	300	0	0

Source: <http://www.sugar-and-sweetener-guide.com/sweetener-values.html>

in view the possible effects on human health. All this has led to the development of various special sugars and other sweeteners including “low-calorie sweeteners”. Higher per capita consumption of sugar in many countries has assumed greater significance keeping in view health-associated issues, of course, for which only sugar consumption may not be held responsible. While it is essential to limit sugar or calorie intake through balanced diet as per WHO guidelines, it would be equally important to improvise food habits and to draw a balance between calorie intake and calorie spent through physical activity.

Table 4.21 Calories per gram, sweetness relative to sugar and glycemic index of modified sugars

S. no.	Name	Calories/ gram	Sweetness index	Glycemic index	Calories/spoon equiv
1	Tagatose	4	0.92	0	7
2	Agave syrup	4	1.5	15	10
3	HFCS-90	4	1.6	31	10
4	HFCS-55	4	1.2	58	13
5	HFCS-42	4	1.1	68	14
6	Golden syrup	4	1.1	60	15
7	Barley malt syrup	4	0.5	42	32
8	Brown rice syrup	4	0.5	25	32

Source: <http://www.sugar-and-sweetener-guide.com/sweetener-values.html>

Table 4.22 Calories per gram, sweetness relative to sugar and glycemic index of artificial sweeteners

S. no.	Name	Calories/ gram	Sweetness index	Glycemic index	Calories/spoon equiv
1	Advantame	0	20,000	0	0
2	Neotame	0	8000	0	0
3	Sucralose	0	600	0	0
4	Saccharin	0	300	0	0
5	Acesulfame K	0	200	0	0
6	Aspartame	4	180	0	0
7	Cyclamate	0	40	0	0

Source: <http://www.sugar-and-sweetener-guide.com/sweetener-values.html>

Note: In this article, mentioning of trade names or commercial goods is solely for providing relevant details and does not indicate recommendation or endorsement by the author.

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